powered space transmitters and the use of spread spectrum modulation techniques. Because the radio astronomy and remote-sensing sensitivities are so great, and terrain shielding cannot be employed, it is most difficult to avoid interference from the sidebands of some spaceborne transmitters, even though their central transmitting frequencies may lie outside the radio astronomy bands.

As long ago as 1960, the vulnerability of radio astronomy to interference was being documented by the International Radio Consultative Committee (CCIR) of the ITU. Estimates of harmful thresholds for radio astronomy bands were published in CCIR Report 224-6. Thus it is now important to implement ways to protect radio-astronomy and other services from adjacent-band interference from air- and space-to-ground transmissions.

As it has in the past, CORF proposes that the bands allocated to the Radio Astronomy Service be afforded protection to the levels given in CCIR Report 224-6. Within these bands, the flux spectral density produced by services in other bands should not exceed these levels. The Radio Astronomy Service, in return, can claim no special privileges with respect to flux spectral density outside its bands except by mutual agreement with other services or by national arrangements.

The concept of a Lunar Quiet Zone has been studied and advanced as a valuable international resource for radio astronomers and for other scientists who are passive observers of the universe. The study of such a quiet zone has been undertaken within the CCIR and has resulted in CCIR Recommendation 479-3. Radio Regulations (RR29) numbers 2632 to 2635 define the shielded zone of the moon and prohibit harmful interference to radio astronomy except in Space Research and Earth Exploration Satellite bands. Work should continue on determination of appropriate protection of this zone.

The Radio Astronomy Service and the Earth Exploration Satellite Service (Passive) were considered at the 1979 WARC. Allocations to these services have allowed continuing useful research programs to be pursued. It is important that future radio conferences not change the Radio Regulations in ways that will be deleterious to these services. Although these services have additional needs, CORF is not pressing for new allocations or considerations at the 1992 WARC. However, the committee would welcome any changes in the regulations that required the use of better and more modern technical standards. CORF especially encourages the development of additional regulations to protect services from emissions spilling over from adjacent bands.

II. SCIENTIFIC BACKGROUND

Radio Astronomy

The fact that radio waves can be received on the earth from celestial objects was first discovered by Karl Jansky of the Bell Telephone Laboratories in 1932, as a by-product of studies of noise in radio-communication systems. Since that time, the science of radio astronomy has expanded to the point that many types of astronomical objects have been studied by radio methods, and many important discoveries have been made.

Whereas the light waves studied by optical astronomers come from hot objects such as stars, celestial radio waves come mainly from cooler objects, such as the gas between the stars, or from electrons in ordered motion. Radio astronomers study many of the same celestial objects that optical astronomers do, and, in addition, their work has revealed new classes of objects and quite unexpected forms of activity. Astronomical studies provide a laboratory in which matter can be seen over a wide range of physical conditions, the extremes of which cannot now or in the foreseeable future be reproduced on the earth. Extremes of density, temperature, and pressure and unusual chemical compositions can all be found at various places in the universe and are under close study by astronomers.

Some of the sources of radio waves are believed to be at the farthest limits of the known universe. Because these sources are so far away, the radio waves have been traveling for many billions of years, the remnants of supernova explosions, and in unusual types of galaxies known as radio galaxies and quasars.

Spectral line radiation is emitted when an atom or molecule gains or loses a discreet amount of energy. This radiation has a specific frequency and wavelength and thus results in a line in the radio spectrum. Each type of atom and molecule has its own unique set of lines. Widely observed spectral lines occur at a frequency near 1420 MHz, arising from neutral (nonionized) hydrogen atoms in the interstellar gas, and at frequencies of 115 and 230 GHz, arising from carbon monoxide molecules. Other spectral lines have been detected from several atomic species and from a large number of molecules found in space and in planetary and stellar atmospheres.

In the solar system, the sun has always been an important object for study by radio astronomers. The slowly varying component of solar radio emission has been found to provide one of the best indicators of the variation of solar activity over the sun's 11-year cycle. In addition, the intense and rapid bursts of solar radio emission are providing greater understanding of what happens on the sun during active periods and the way the sun influences events in the earth's atmosphere, near-earth space, and other portions of the solar system.

The planet Jupiter also produces frequent bursts of radio waves, and it was the study of these by radio astronomers that first showed the coupling between Jupiter's magnetosphere and the satellite Io. This has been confirmed and extended by measurements in the vicinity of Jupiter from the Pioneer and Voyager spacecrafts.

Radio astronomy has provided new information about the early and late stages of the lives of stars, stages that are important in the evolutionary process but that are not well understood. Strong and localized sources of radiation in spectral lines of the hydroxyl and water molecules are found in the shells of objects that appear to be in the process of becoming stars. Some compact sources of thermal continuum radiation, which are embedded in dense clouds of dust, also seem to be protostellar objects. Recently, giant breeding grounds of massive new stars, and dark clouds where stars similar to the sun are born, have been detected. Millimeter and submillimeter radio telescopes and interferometers are expected to lead astronomers to a new era of understanding of the star formation process.

At the other end of the stellar life cycle, radio astronomers study supernova remnants, the material blown out from massive stars in giant explosions at the end of their lives as stars. Radio astronomers have also discovered numerous very dense and compact neutron stars, which are the remnants of supernova explosions. A rapidly rotating neutron star often is observed as a pulsar, a periodic radio source, which emits a narrow beam of coherent radiation as the neutron star rotates. The period of some pulsars is of the order of a millisecond, making these objects the most stable clocks known.

Spectral lines have now been detected from about 80 different molecules in interstellar space. Many of these are organic molecules, and some are quite complex. These discoveries have raised interesting questions about how complex molecules have been built up and how further development might lead to the precursors of life, as a possibly widespread phenomenon in our galaxy and the wider universe. Astronomers, who study astrochemistry, attempt to trace out the development of a chain of chemical compounds by searching for the appropriate spectral lines. To study the physical conditions inside a molecular cloud, or in different portions of the cloud, it is necessary to compare the relative strengths of lines from different molecules, or of different transitions (lines) from the same molecule. In some cases, a set of lines of a particular type of molecule, involving different isotopes of one or more of the constituent atoms (hydrogen, carbon, nitrogen, or oxygen), can be studied; these studies can give valuable information on the relative densities of the various isotopes in the interstellar medium, and thus indirectly on the general evolution of the chemical elements.

Studies of some spectral lines are more important than others because the atoms or molecules concerned occur in greater numbers, the transitions are more easily excited, or they are particularly good for indicating the conditions inside a cloud or the location of the spiral arms in a galaxy. However, to understand the chemical and physical conditions properly, it is necessary to intercompare a large number of lines.

Studies of galaxies depend heavily on observations of spectral lines at radio wavelengths. These observations provide information on the kinematics of the gas in the galaxies and on the abundance of the elements making up that gas. The hydrogen line has been used to learn about the gravitational potential of the galaxies, leading to the realization that a substantial fraction of the masses of galaxies is made up of material that is not visible. This is called the "missing mass" problem and is vital information in deciding whether the universe will expand forever or will eventually collapse on itself. Further, the hydrogen spectra of galaxies is used for determining their distances and therefore helping to establish the large-scale structure of the universe.

Many distant galaxies are unusually strong continuum emitters of radio waves but are relatively faint when viewed with an optical telescope. These "radio galaxies" are the subject of many investigations attempting to discover the source of their radio energy and the circumstances of the explosive events that seem to have occurred in many of them.

The most powerful radio sources known are quasars, which are distant, compact objects that emit radio energy at a prodigious rate. A quasar is believed to be the nucleus of a galaxy that is usually too distant for anything but the central core to be seen. The study of quasars involves fundamental physics, in the continuing attempt to understand their sources of energy. The nuclei of some other classes of galaxies show great activity and unusual energy production. Even the nucleus of our own galaxy is a small-scale version of an active nucleus and can best be studied by radio methods.

Remote Sensing of the Earth

Observations of the earth's atmosphere, land areas, and oceans in the radio part of the electromagnetic spectrum have become increasingly important in understanding the earth as a system. Currently operational satellite instruments, including the Microwave Sounding Unit (MSU) and instruments on the U.S. Air Force's passive microwave weather satellites (SSM/I and SSM/T) provide key meteorological data sets. Future remote-sensing satellite missions such as NASA's Earth Observing System (EOS) and the Tropical Rainfall Measurement Mission (TRMM) are currently under planning. The missions are expected to improve measurements of atmospheric temperature, water vapor and precipitation, soil moisture, concentrations of ozone and other trace gases, and sea surface temperature and salinity. These multiyear, multibillion-dollar missions are international in scope, reflecting the interests of many countries in obtaining accurate meteorological, hydrological, and oceanographic data, and measurements of land surface features and trace gases in the atmosphere.

The outcome of such remote sensing missions will be improvements in weather forecasting; severe storm monitoring; water resource, land, and biota management; and improved global climate and atmospheric chemistry models. The long-term economic impact of the information from remote sensing satellites promises to be substantial, in both the production of food and other agricultural products and the operation of businesses and industries that are dependent on both local weather and long-term climate stability. A substantial number of lives can be saved through advanced warning of dangerously inclement weather. The remotely sensed information will also be used to provide scientifically based guidelines for environmental policy.

Passive Sensors

A major component of earth remote sensing systems consists of spaceborne passive microwave radiometers. These sensors are similar in their basic design and sensitivity to radioastronomy receivers and are essential to the overall success of satellite-based earth remote sensing missions, due to their ability to probe through optically thick clouds. This unique feature of passive microwave sensing complements the capabilities of infrared and optical sensors.

As in radioastronomy, bands near certain atmospheric spectral lines and transmission windows are required for passive earth exploration satellites. Several bands, listed in Tables 1 and 2, have been identified and investigated for their particular capabilities. Atmospheric temperature profiles can be measured using channels near O_2 absorption lines at 50-70 GHz (within the 5-mm absorption band) and at 118 GHz. Water vapor profiles can be measured using channels near H_2O absorption lines at 22.235 and 183.310 GHz, and potentially at 325 GHz. Precipitation exhibits no narrow spectral features and thus requires a widely spaced set of channels for observation. Useful channels are near 6, 10, 18, 37, 90, 157, and (potentially) 220 and 340 GHz.[1] Soil moisture measurement requires a low-frequency microwave channel near 1 to 3 GHz. Sea surface temperature and wind speed measurements require channels at slightly higher frequencies, near 6, 10, and 18 GHz. Concentrations of atmospheric trace gases (e.g., ozone) can be measured by observing atmospheric radio emissions near molecular resonances.

The required sensitivities for retrieval of geophysical parameters are listed in Table 1, in terms of the required accuracy of the brightness temperature values, which range from 0.1 to 1.0 K. In order to obtain these sensitivities, wide bandwidths (from 60 MHz to 6 GHz) are required. The particular bandwidth requirement depends on the use of the channel, the receiver sensitivity, and the observation time; minimum acceptable bandwidths are given in Table 1. The listed bands are consistent with CCIR Recommendation 515, "Frequency Bands and Performance Requirements for Satellite Passive Sensing," although wider bandwidths are suggested for some frequencies.

In order to obtain the sensitivity required for earth remote sensing, interference from radio sources must be kept below the thresholds described in CCIR Report 694. The current allocations for passive earth exploration satellites were made during the 1979 WARC.

Active Sensors

Another critical component of current and planned earth remote sensing systems consists of active spaceborne sensors, such as synthetic aperture radars (SARs), radar altimeters, and precipitation radars. Uses of active sensors include measurement of soil moisture, snow, ice, rain, clouds, atmospheric pressure, and ocean wave parameters, and mapping of geologic and geodetic features and vegetation.

Suggested channels for active earth remote sensing are 100-MHz-wide frequency bands near 1, 3, 5, 10, 14, 17, 35, and 76 GHz. Wider bandwidths (up to 600 MHz) are required for altimeter measurements with vertical resolution less than 50 cm. These bands are consistent with CCIR Recommendation 577-1,

[1]The High Resolution Multifrequency Microwave Radiometer, part of NASA's planned Earth Observing System (EOS), includes the Advanced Microwave Sounding Unit, which will provide atmospheric soundings of temperature and water vapor using channels in the oxygen resonance band (50-60 GHz) and the water vapor line at 183 GHz; the Advanced Mechanically Scanned Radar, a microwave imager operating at 6, 10, 18, 21, 37, and 90 GHz; and the Electronically Scanned Thinned Array Radiometer, an imaging radiometer that operates at 1.43 GHz.

"Preferred Frequency Bands for Active Sensing Measurements." The current allocations for active earth remote sensing were made during the 1979 WARC.

TABLE 1 Passive Earth Exploration Channels (after CCIR Recommendation 515)

Frequency (GHz)	Suggested Bandwidth (MHz)	Required Accuracy (K)	Measurements
Near 1.4	100	0.1	soil moisture
Near 2.7	60	0.1	salinity, soil moisture
Near 5	200	0.3	estuarine temperature
Near 6	400	0.3	ocean temperature, rain
Near 10	100	1.0	rain, snow, ice, sea state
Near 15	200	0.2	water vapor, rain
Near 18	200	0.2	rain, ocean ice, water vapor, sea state
Near 21	200	0.2	water vapor, rain
22.235	300	0.4	water vapor, rain
Near 24	400*	0.2	water vapor, rain
Near 31	500	0.2	ocean ice, oil spills, rain, clouds
Near 37	1000	0.7	rain, snow, ocean ice, water vapor, sea state
50-61.5	250†	0.1	temperature
64-66	100†	0.1	temperature
Near 90	6000*	0.7	clouds, oil spills, ice, snow
100.49	2000	0.2	nitrous oxide
110.80	2000*	0.2	ozone
115.27	2000	0.2	carbon monoxide
118.75	6000¶	0.1	temperature
125.61	2000	0.2	nitrous oxide
150.74	2000	0.2	nitrous oxide
Near 157	2000	0.7	rain, cloud water, water vapor
164.38	2000	0.2	chlorine oxide

Continued

TABLE 1 (*Continued*)

Frequency (GHz)	Suggested Bandwidth (MHz)	Required Accuracy (K)	Measurements
Near 166	4000*	0.7	rain, cloud water, water vapor
167.20	2000	0.2	chlorine oxide
175.86	2000	0.2	nitrous oxide
183.31	18,000¶	0.1	water vapor, clouds
184.75	2000	0.2	ozone
200.98	2000	0.2	nitrous oxide
Near 220	6000*	0.7	rain, clouds
226.09	2000*	0.2	nitrous oxide
230.54	2000	0.2	carbon monoxide
235.71	2000	0.2	ozone
237.15	2000	0.2	ozone
251.21	2000*	0.2	nitrous oxide
276.33	2000	0.2	nitrous oxide
301.44	2000	0.2	nitrous oxide
325.10	18,000¶	0.1	water vapor, clouds
Near 340	6000	0.5	water vapor, clouds
345.80	2000	0.2	carbon monoxide
364.32	2000	0.2	ozone
380.20	2000	0.2	water vapor
Near 420	6000	0.5	water vapor, clouds
424.76	6000	0.1	temperature, clouds

NOTE: Center frequencies and bandwidths have been modified for some channels.

*The current frequency allocation is acceptable.
†Several O_2 channels lie within this range.
¶Several double sideband channels are centered around the absorption line peak within this range.

TABLE 2 Microwave Frequencies Utilized by the National Oceanic and Atmospheric Administration

Channel Number	Center Frequency	Bandwidth (MHz)	Stability (MHz)	NEDT (K)
1	23.8 GHz	270	10	0.3
2	31.4 GHz	180	10	0.3
3	50.3 GHz	180	10	0.4
4	52.8 GHz	400	5	0.25
5	53.596 GHz	170	5	0.26
6	54.4 GHz	400	5	0.25
7	54.94 GHz	400	5	0.25
8	55.5 GHz	330	10	0.25
9	57.290344 GHz=f_{LO}	330	0.5	0.25
10	f_{LO} ±217 MHz	78	0.5	0.4
11	f_{LO} ±322.2 ±48 MHz	36	0.5	0.4
12	f_{LO} ±322.2 ±22 MHz	16	0.5	0.6
13	f_{LO} ±322.2 ±10 MHz	8	0.5	0.8
14	f_{LO} ±322.2 ±4.5 MHz	4	0.5	1.2
15	89.0 MHz	6000	50	0.5
16	60.79267 ±0.3539 GHz	3	0.03	1.5
17	60.79267 ±0.3558 GHz	0.8	0.03	2.8
18	60.79267 ±0.3569 GHz	0.5	0.03	3.5
19	60.79267 ±0.3579 GHz	1.0	0.03	2.5
20	60.79267 ±0.3589 GHz	0.5	0.03	3.5
21	60.79267 ±0.3600 GHz	0.8	0.03	2.8
22	89.0 GHz	6000	50	1.0
23	157.0 GHz	4000	50	1.0
24	183.31 ±1.0 GHz	1000	50	1.0
25	183.31 ±3.0 GHz	2000	50	1.0

Searching for Evidence of Extraterrestrial Technologies

In 1959, Cocconi and Morrison published a paper suggesting that the technology of radio astronomy had progressed to the point that interstellar communication between ourselves and a very distant civilization might be possible. They suggested the 1420-MHz line of neutral hydrogen as an obvious universal communication channel. Independently, Frank Drake made the first radio search for extraterrestrial intelligence (SETI) using the Tatel telescope of the National Radio Astronomy Observatory equipped with a single-channel, narrowband spectrometer and a receiver tuned to 1420 MHz. Project OZMA, as this search was called, was conducted in the spring of 1960 and examined two nearby solar-type stars for a few hundred hours. It was the first of nearly 60 searches that have been made over the past three decades, most of them at radio frequencies.

Footnote 722, added to the Radio Regulations during the 1979 WARC, recognizes the interest of the radio science community in this passive search technique. Since 1960, improvements in receiver technology and digital signal processing equipment, intended primarily for use in radio astronomy, have enabled far more sensitive and sophisticated searches for extraterrestrial technologies to be conducted. Making use of the receiver instrumentation developed for radio astronomy, these searches have remained clustered about the frequencies of natural atomic and molecular emission lines and within the protected radio astronomy bands. Plausible arguments can be made for searching at these "magic frequencies," but most of the microwave window has remained unexplored. We can of course only speculate on the likelihood of civilizations with matching technology.

Starting in 1992 NASA will inaugurate a systematic search for signals throughout the 1- to 10-GHz frequency range that represents the clearest microwave window through the terrestrial atmosphere. This search will be based on state-of-the-art signal processing equipment and wideband, low-noise receivers and feeds developed specifically for SETI. The search will be conducted with two complementary strategies, a targeted search of the nearest 1000 solar-type stars using the world's largest radio telescopes and an all-sky survey using the 34-meter antennas of NASA's Deep Space Network. Although this search will be billions of times more comprehensive than even the most ambitious search currently under way—the META projects of the Planetary Society using dedicated telescopes in Massachusetts and Argentina—it is still a limited search and may not succeed.

Because of the technical challenges alone, SETI is an important scientific endeavor. SETI experiments require advanced methods of signal processing as an attempt is made to recognize and interpret weak signals of unknown intensity, frequency, and temporal characteristics amidst a background din of terrestrial and cosmic noise. As with more traditional astronomical studies of weak cosmic radio emission, terrestrial interference poses the greatest challenge to this microwave search. If all the frequencies are to be observed for all the targets and directions on the sky, techniques will have to be found to mitigate against, or work around, the ground-based and satellite transmissions from all the active services making use of the 1- to 10-GHz frequency range. If the search is unsuccessful, future searches may need to be conducted from the Lunar Quiet Zone on the lunar far side (see Chapter VI). As with traditional radio astronomy and remote sensing of the earth, SETI would benefit greatly from the adoption of modern technical standards and the reduction of out-of-band emissions from active services.

Technological Contributions

The history of radio astronomy and earth remote sensing has shown a remarkable rate of important and unexpected discoveries. In the short period of the last four decades, radio scientists have made fundamental new discoveries in physics and have brought us closer to understanding both the nature of the universe and our immediate environment. The rapid rate of important discoveries in radio astronomy and atmospheric science will surely continue. Such progress is assured in part by protecting radio-frequency bands for the passive services.

Radio astronomy and remote sensing have contributed to the development of practical devices and techniques. Some of these are listed below:

- The development of very-low-noise receivers with system temperatures as low as 10 K and frequencies extending from a few MHz to 1000 GHz. These have wide applications in radio technology.
- The study of the thermography of the body by use of millimeter radio techniques (~45 GHz).
- The detection of breast cancer at centimeter wavelengths (~10 GHz) with modern radiometers.
- Computerized x-ray tomography, which employs methods originally developed for mapping radio sources.
- The detection of forest fires by their microwave radiation.
- The identification of potential earthquake zones by very-long-baseline interferometric (VLBI) measurements of fault motion.
- The determination of many geophysical parameters such as continental drift, polar wandering, latitude measurements, and variations in the earth's rotation, with the use of connected-element and VLBI techniques.
- Major contributions to navigation—including that of spacecraft—and timekeeping resulting from pulsar observations, VLBI, and the verification of Einstein's general theory of relativity.
- Measuring the temperature of the earth's atmosphere, surface properties, and the distribution of water vapor, cloud water, precipitation, and impurities such as carbon monoxide by passive remote-sensing techniques.
- Monitoring of trace gases, such as ozone, important to atmospheric chemistry.

Radio astronomy is an active and vigorous science, in which the universe and its component parts are studied and new discoveries made at a rapid rate. The foregoing account is a selection of only a few examples. To continue this rapid advance, it is necessary to operate many radio observatories with different instruments and locations, including space, and to be able to observe at many different frequencies. Countries around the world that have devoted large sums of money for the development of radio astronomy include Argentina, Australia, Brazil, Canada, China, Germany, France, India, Italy, Japan, The Netherlands, the United Kingdom, the United States, and the U.S.S.R. It is anticipated that this support will continue and that other countries will start major radio-astronomical projects.

III. GENERAL CONSIDERATIONS ON FURTHER PROTECTION

In the remarks below, specific frequencies actually refer to frequency bands.

1. The gap between the 74-MHz and the 408-MHz continuum allocations is too broad. A frequency band in the range 130-250 MHz with a 1- to 2-percent bandwidth is urgently needed. Footnote protection, at least, should be provided. The band 150.05 to 153 MHz is protected in Region 1. Such a frequency allocation would be especially useful for pulsar research and for VLBI.

2. The 1979 WARC provided an allocation for the passive services in the 322-328.6 MHz band. This band serves both line and continuum observations, since it includes the hyperfine transition from the cosmologically significant deuterium atom. This has become an important band for radio astronomers all over the world, with its use for VLBI and on the Very Large Array (VLA). However, this band is not allocated to the passive services in the United States.

3. The 608-614 MHz band has different detailed allocations for each region. A single worldwide band is desired to allow pursuit of international VLBI observations. Coordination with television transmissions on adjacent channels would be desirable.

4. The primary, exclusive allocation in the 1400-1427-MHz band should be preserved for studies of neutral atomic hydrogen and for passive earth remote sensing of soil moisture. Additional protection in the 1330-1400-MHz band is also required for studies of distant galaxies.

5. Important spectral lines should have their allocation status upgraded to "Primary" in the allocation table. This is particularly pertinent in the case of the OH lines at 1612 MHz, and 1720 MHz. The bandwidths should be at least wide enough to cover the expected Doppler-shift range found in our galaxy.

6. The 2695-MHz (11-centimeter) band is important to radio astronomy. Its bandwidth is small considering its relative importance, and efforts should be made to increase this bandwidth. This frequency band is also useful for passive remote sensing of the earth's surface parameters.

7. The allocation status for the H_2CO line at 4830 MHz should be upgraded to "Primary" in the allocation table. The bandwidths should be at least wide enough to cover the expected Doppler-shift range found in our galaxy.

8. The 4990-MHz (6-centimeter) band has become one of the most important for continuum radio astronomy. The frequency is used in almost all observatories as a primary frequency for continuum and VLBI measurements. Improved protection in the 4800-4990-MHz band is desirable.

9. The water vapor and ammonia lines at 22.2 GHz and around 23 GHz are important diagnostic lines of the interstellar medium of our galaxy and other galaxies. The protection of these lines needs to be improved.

10. The continuum bands above 80 GHz now allocated to the Radio Astronomy Service and the Earth Exploration Satellite Service are particularly useful because they have large enough bandwidths to take full advantage of modern receiver technology, and they are situated in regions of the spectrum where atmospheric windows exist.

11. In general, a 1- to 2-percent bandwidth is the minimum practical allocation; a 5-percent bandwidth would be desirable for the continuum bands. This is strongly reinforced by the new and rapidly increasing requirements for bandwidth allocation at all frequencies, for complex molecular line studies in the galaxy and for red-shifted lines of distant galaxies. This requirement can be met by the use of the same fractional bandwidth allocations for spectral lines as for continuum astronomy as long as the allocated bands occur reasonably frequently throughout the full spectrum.

12. In the last 30 years, radio astronomy studies have demonstrated the presence of ever-more-complex molecules in interstellar space. These discoveries have been one of the most fascinating and puzzling developments in the field. The complexity of the largest molecules already exceeds that of simple amino acids. It is anticipated that, in the future, still more complex molecules, and possibly amino acids, will be found. Identification of complex molecules can be made only by detection of a number of radio lines.

13. Passive services have considered, in a preliminary fashion, those spectral lines at frequencies above 275 GHz that may merit the granting of protection at some future WARC. Since the 1992 WARC will not address this frequency range, it is not discussed in this document. The most important spectral lines for radio astronomy are listed in CCIR Recommendation 314-7. This list is developed and updated regularly by a working group within the International Astronomical Union.

14. Strong efforts must be made to protect radio astronomy bands from adjacent band interference from air- or space-to-ground transmissions. Table 3 shows the potential interference situation from air- or space-to-ground transmission adjacent to the primary radio-astronomy bands. Passive services are particularly sensitive to spurious, out-of-band and harmonic emissions from other services. A major effort to modernize and upgrade engineering standards for active services should be made, especially with regard to out-of-band emissions. Modernization of these standards would be useful to other services as well as to radio astronomy. This is particularly the case with airborne and satellite transmitters and devices that do not require licensing.

TABLE 3 Services in Adjacent Bands That Could Cause Harmful Interference to the Radio Astronomy Service

Band Allocated to Radio Astronomy on a Worldwide	Adjacent Band	Adjacent-Band Services

TABLE 3 *(Continued)*

Band Allocated to Radio Astronomy on Worldwide Primary Basis	Adjacent Band	Adjacent-Band Services
31.3-31.8 GHz	31-31.3 GHz	MOBILE Standard signals-Satellite (space-to-earth) Space research
	31.8-32 GHz	RADIONAVIGATION Space research
42.5-43.5 GHz	40.5-42.5 GHz	BROADCASTING-SATELLITE Mobile
	43.5-47 GHz	MOBILE MOBILE-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE
86-92 GHz	84-86 GHz	MOBILE BROADCASTING-SATELLITE
	92-95 GHz	MOBILE RADIOLOCATION
105-116 GHz	102-105 GHz	FIXED-SATELLITE (space-to-earth) MOBILE
	116-126 GHz	INTER-SATELLITE (space-to-earth) MOBILE
164-168 GHz	151-164 GHz	FIXED-SATELLITE (space-to-earth) MOBILE
	168-170 GHz	MOBILE
182-185 GHz	176.5-182 GHz	INTER-SATELLITE MOBILE
	185-190 GHz	INTER-SATELLITE, MOBILE
217-231 GHz	202-217 GHz	MOBILE
	231-235 GHz	FIXED-SATELLITE (space-to-earth) MOBILE Radiolocation
265-275 GHz	252-265 GHz	MOBILE MOBILE-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE

NOTE: Fixed and mobile services, except aeronautical mobile services, are not included.

*Under study (see Resolution No. 505 of WARC-79).
†See also footnote 730A (MOB-87) of the Radio Regulations.

IV. SPECTRAL LINE PRIORITIES FOR RADIO ASTRONOMY

The International Astronomical Union (IAU) has a special working group dedicated to a periodic review and update of the list of spectral lines of greatest interest to astronomers. The list is updated every three years. The CORF has followed the IAU list for the most part in creating Tables 4 and 5, which list Priority 1 and Priority 2 spectral lines, respectively. (Lines of interest for remote sensing and atmospheric research are discussed in Table 1.)

In general, the committee believes that Priority 1 lines merit unshared, passive exclusive allocations. These are lines that give us information about important and widespread astrophysical phenomena, including astrochemical reactions. Priority 2 lines are often not so well understood or studied but because of their potential for wider study deserve at least footnote protection.

TABLE 4 Priority 1 Spectral Lines

Spectral Line Frequencies	Atomic and Molecular Species
1420.406 MHz	Hydrogen [The allocation 1330-1427 MHz is needed to permit observations of hydrogen in our galaxy and other nearby galaxies with radial velocities up to 20,000 km/s.]
1612.231, 1665.402, 1667.359, and 1720.530 MHz	OH (hydroxyl radical)
4829.660 MHz	H_2CO (formaldehyde)
12.178 GHz	Methanol
22.235 GHz	H_2O (water vapor)
23.694, 23.723, and 23.870 GHz	NH_3 (ammonia)
48.991 GHz	CS (carbon sulphide)
86-92 GHz	Numerous lines, including HCN (hydrogen cyanide) and its ^{13}C, ^{17}O, and ^{18}O isotopes; HNCO (isocyanic acid); formylium HCO^+; HNC (hydrogen isocyanide); and SiO (silicon monoxide)
97.981 GHz	CS (carbon sulphide)
109.782, 110.201, 112.359, and 115.271 GHz	CO (carbon monoxide, including ^{13}C, ^{17}O, and ^{18}O isotopes)
113.14-113.51 GHz	Several transitions of CN (cyanogen radical, including ^{15}N and ^{13}C isotopes)
183.310 GHz	H_2O (water vapor)
219.560, 220.399, and 230.538 GHz	CO (carbon monoxide, including ^{13}C and ^{18}O isotopes)
265.886 GHz	HCN (hydrogen cyanide)
267.557 GHz	HCO^+ (formylium)
271.981 GHz	HNC (hydrogen isocyanide)

TABLE 5 Priority 2 Spectral Lines

Spectral Line Frequencies	Atomic and Molecular Species
327.384 MHz	Deuterium [While this line has not yet been detected with confidence, it is known that deuterium is present in the interstellar medium. When the line is detected, it will certainly merit inclusion in the Priority 1 list.]
3263.794, 3335.481, and 3349.193 MHz	CH
14.488 GHz	H_2CO (formaldehyde)
22.834, 23.098, and 24.139 GHz	NH_3 (ammonia)
42.821, 43.122, and 43.424 GHz	SiO (silicon monoxide)
72.409 GHz	H_2CO (formaldehyde)
93.17 GHz	N_2H^+ (dinitrogen hydronium)
140.840, 145.603, and 150.498 GHz	H_2CO (formaldehyde)
144.8207 GHz	DCN (deuterated cyanide)
174.6-174.85 GHz	C_2H
177.2 GHz	HCN (hydrogen cyanide)
178.4 GHz	HCO^+ (formylium)
181.2 GHz	HNC (hydrogen isocyanide)
186.4 GHz	N_2H^+ (dinitrogen hydronium)
279.511 GHz	N_2H^+ (dinitrogen hydronium)

V. PASSIVE SERVICE ALLOCATIONS AND THEIR JUSTIFICATION

The following comments are ordered according to increasing frequency of the band concerned.

Comments

1. 13.36-13.41 MHz: This band was allocated to the Radio Astronomy Service by the World Administrative Radio Conference in 1979 (WARC-79). It has proved useful for a number of investigations that previously were impossible because of a lack of protection. The allocation is shared on a primary basis with the Fixed Service worldwide and on a primary exclusive basis in the United States.

2. 25.55-25.67 MHz: This band was allocated to the Radio Astronomy Service on a primary exclusive basis by WARC-79. This band is especially useful for observations of the sun and radio bursts from Jupiter (caused by interactions with its moon Io).

3. 37.50-38.25 MHz: This allocation was modified only slightly by WARC-79. On a worldwide basis the Radio Astronomy Service has a secondary allocation shared with the Fixed and Mobile Services. In the United States the band 38.00-38.25 MHz is shared on a primary basis with the Fixed and Mobile Services. Despite the secondary allocation, this band is often free of interference and is quite useful for radio astronomy. It should be broadened and changed to a primary, exclusive allocation worldwide.

4. 73.0-74.6 MHz: This primary exclusive allocation for the Radio Astronomy Service applies only in Region 2 (before WARC-79 it also applied in Region 3). Observations with the Arecibo 305-m radio telescope may be affected by active use of this band by the Fixed and Mobile Services in Cuba and other countries included in Footnote 570. A primary exclusive allocation on a worldwide basis is highly desirable; notification of use is required in Regions 1 and 3 (Footnote 568), and in Region 3 (with some exceptions) the band 79.75-80.25 MHz is allocated on a primary basis to the Radio Astronomy Service.

Justification (1, 2, 3, 4)

Most radio sources (such as radio galaxies, quasars, and supernova remnants) have characteristic nonthermal spectra produced by synchrotron emission from relativistic cosmic-ray electrons moving in galactic-scale magnetic fields. These nonthermal sources typically have radio spectra with negative slopes of ~0.8 in a graph of log (flux density) versus log (frequency). Hence such sources have higher radio flux densities at lower frequencies. The hundreds of pulsars in the Milky Way Galaxy (rotating neutron stars that act as giant particle accelerators) also have nonthermal radio spectra that have even more negative slopes and higher relative flux densities at low frequencies. However, at sufficiently low frequencies (10-100 MHz), the emission processes, conditions in the radio sources, or conditions in the surrounding environments cause the spectra of these radio sources to turn over or decrease with frequency (see Figure 1). Measuring the low-frequency spectra of such sources is essential for measuring and understanding their physical properties.

This low-frequency range also has a great importance in the observations of both the thermal and nonthermal diffuse radiation in our own Milky Way Galaxy. Such galactic observations give information on the high-energy cosmic ray particles in our galaxy and their distribution, and also on the hot ionized plasma and star birth in the disk of our spiral galaxy. In particular, the ionized interstellar clouds can be studied at low frequencies where their spectra approximate the Planck thermal radiation (blackbody) law. Several hundred such galactic clouds appear approximately as blackbodies at frequencies below ~100 MHz. Such spectral observations can be used directly to measure the physical parameters of the radiating clouds, particularly their temperatures.

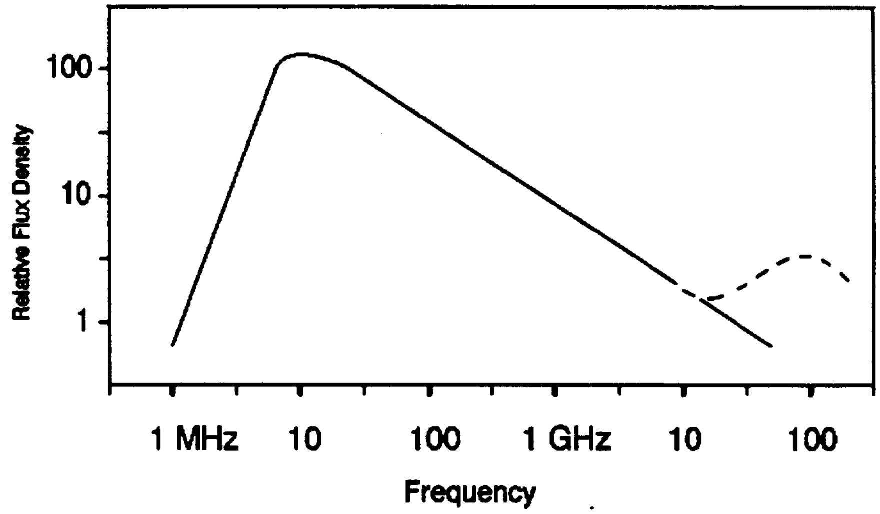

FIGURE 1 Spectrum of a typical nonthermal radio source. The dashed line shows the "compact" high-frequency component found in some sources.

Other important radio observations made at frequencies below ~100 MHz are those of solar bursts. Occasionally, and frequently during sunspot maximum, dramatic radio bursts of several different characteristic types are generated in the sun's atmosphere. Such bursts are sometimes associated with solar flares, which are sudden violent explosions in the sun's chromosphere. The radio bursts are observed from ~20 to ~400 MHz and are more intense at the lower frequencies. The high-energy particles ejected from the sun during these bursts interact with the earth's ionosphere and the stratosphere. Such interactions cause severe interruptions in radio communications and power systems, and can also have dangerous effects on aircraft flights above 15,000 meters. Studies of radio bursts aim to allow us to predict failures in radio communications and to forecast other effects. Knowledge of the high-energy particle ejections from the sun is essential for space exploration missions, both manned and unmanned. Continuous monitoring of the sun's activity will remain a high priority for the foreseeable future.

Also significant is the peculiar nonthermal burst-like radiation from the giant planet Jupiter, which is best observed at frequencies from ~15 to ~40 MHz. Extensive observations are being made at low frequencies in order to study this peculiar radiation. It was observed by the Voyager spacecraft, but further ground-based studies are essential.

These four allocations have proven to be invaluable for radio astronomy. They would be even more valuable if all four were allocated to the Radio Astronomy Service on a primary exclusive basis that extended to all three regions.

Comments

5. 150.05-153 MHz: This is a shared, primary allocation in Region 1. It falls near the middle of a wide gap in continuum coverage (see No. 3 in the "General Considerations" above). In the United States, a large amount of interference occurs in this band. A continuum band is badly needed between the current 74 and 408 MHz allocations, and it may be possible to have Regions 2 and 3 join Region 1. This band is widely used in the United Kingdom and is a major band for the Giant Meter-Wave Radio Telescope (GMRT) in India. Further worldwide consolidation would be most desirable.

6. 322-328.6 MHz: This important band gained additional status at WARC-79 and has become a widely used band throughout the world. It has now been implemented on the VLA and is widely used for VLBI experiments between countries (see No. 2 in the "General Considerations" above). It is not allocated to the passive services in the United States.

7. 406.1-410 MHz: This is an important continuum band where regional protection (U.S. 117) is often necessary. Additional allocation up to 414 MHz would be desirable.

8. 608-614 MHz: Extension of the primary allocation from Region 2 to Regions 1 and 3 would be desirable. A continuum band such as this one is needed between the 408 and 1400-1427 MHz bands. Better protection from adjacent channel interference is badly needed. The band is also used by the GMRT in India.

Justification (5, 6, 7, 8)

One of the most interesting and significant discoveries in radio astronomy has been the detection of pulsars. These objects are now understood to be highly condensed neutron stars that rotate with a period as short as a millisecond. Such objects are produced by the collapse of the cores of very old stars during the catastrophic explosions known as supernova outbursts. The radio spectra of pulsars indicate a nonthermal mechanism, perhaps of synchrotron emission type. Observations have shown that the pulsars are strongest at frequencies in the range from ~50 to 600 MHz; hence, most of the pulsar observations are being performed at such frequencies. With improved sensitivities at higher frequencies, these sources are now observed at up to several gigahertz.

The discovery and the study of pulsars during the last two decades have opened up a major new chapter in the physics of highly condensed matter. The study of neutron stars with densities of the order of 10^{14} g/cm^3 and with magnetic-field strengths of 10^{12} gauss has already contributed immensely to our understanding of the final state in stellar evolution and has brought us closer to understanding black holes (which are thought to be the most highly condensed objects in the universe). Observations of binary pulsars have verified the existence of gravitational radiation at the level predicted by the theory of relativity. Low frequency bands 6-8 are indeed important for pulsar observations. The need for exclusive bands at every octave is clearly indicated.

The frequency band 322-328.6 MHz has the desired octave-spacing relation with the 150.05-153 MHz and 608-614 MHz bands. Large radio telescopes in India, The Netherlands, and the United States at the Arecibo telescope in Puerto Rico, as well as the VLA and the Very Long Baseline Array (VLBA), operate in this band. High-resolution observations of radio galaxies and quasars have been made with the antenna in India using the method of lunar occultations. This method uses the moon's disk, which occults distant radio sources as its apparent position changes on the sky. From such occultations, or eclipses, it has been possible to determine the shapes and positions of many extragalactic radio sources with very high accuracies, of the order of 1 arc second.

The frequency range 322-328.6 MHz also contains the hyperfine-structure spectral line of deuterium at 327.4 MHz, the discovery of which astronomers consider highly significant. The abundance of deuterium relative to that of hydrogen is related to the problems of the origin of the universe and the synthesis of the elements. A determination of the deuterium abundance in the universe will certainly help in defining the most probable theory of the origin and evolution of the universe. Ultraviolet observations of deuterium show that its abundance in space is not constant, suggesting that studies of its abundance may be of increasing significance.

Many observatories, worldwide, have added 327-MHz receivers to their telescopes. This has become a major new frequency for VLBI observations between continents. The Westerbork Synthesis Radio Telescope in The Netherlands and the VLA in the United States have been equipped for operation in this band. Japanese radio astronomers have constructed a three-station array for observations of interplanetary scintillation near 327 MHz. In the United States, the band is being used at Owens Valley and Hat Creek for deuterium searches. U.S. radio astronomers certainly support efforts to protect this band. The band is also used by the GMRT in India.

Comments

9. 1330-1400 MHz: This band is important for observations of red-shifted neutral hydrogen gas from external galaxies and has footnote protection. The lower-frequency limit for footnote 718 should be decreased to approximately 1250 MHz. Successful observations of red-shifted neutral atomic hydrogen have already been made in a quasi-continuous range of frequencies down to 1260 MHz. Below this frequency, such detections have been made only at individual, isolated frequencies.

10. 1400-1427 MHz: This is the most important band for hydrogen-line observations and is also important for continuum observations. Extending the worldwide exclusive allocation downward in frequency to 1330 MHz would greatly benefit radio astronomy by allowing observations of distant, red-shifted hydrogen clouds. The extension of the allocated 1400-1427 MHz band to 1330-1427 MHz would also benefit passive remote sensing of the earth's soil moisture.

Justification (9, 10)

One of the most important spectral lines at radio wavelengths is the 21-centimeter line (1420.406 MHz) of neutral atomic hydrogen. Since its discovery in 1951, radio observations of this line have been used to study the structure of our galaxy and other galaxies. Because of Doppler and cosmological shifts due to the distance and motion of the hydrogen clouds that emit this radiation, the frequency for observing this line emission ranges from ~1330 to ~1430 MHz. Numerous and detailed studies of the neutral hydrogen distribution in our galaxy and in other galaxies are being made. Such studies are being used to investigate the state of cold interstellar matter, the dynamics, kinematics, and distribution of the gas, the rotation of our galaxy and other galaxies, and the masses of other galaxies.

The 21-centimeter neutral hydrogen emission is relatively strong, and with current receiver sensitivity such emission is detectable from any direction in our galaxy and from a very large percentage of the nearby galaxies.

In recent years, the physics of the ionized hot gaseous clouds between the stars has been studied by observations of radio lines of excited hydrogen, helium, and carbon. Some of these studies have been made at frequencies of 1399 and 1424 MHz. Detailed observations of radio recombination lines in many interstellar clouds have made possible the derivation of physical parameters such as temperature, density, and velocity distributions. Radio studies have been particularly helpful for observations of these clouds, which are partially or totally obscured at optical wavelengths by interstellar dust.

Comments

11. 1610.6-1613.8 MHz: The 1612-MHz transition is an extremely important satellite line of OH. This line emission occurs in many types of objects in the galaxy, and high-angular-resolution observations of these objects in this line measure their distances and can be used collectively to measure the distance to the center of the galaxy. The secondary allocation should be considerably strengthened or a narrow, worldwide allocation made. See Comment 12.

12. 1660-1670 MHz: To afford the level of protection needed in order to observe the primary OH lines properly, CORF urges exclusive allocation for radio astronomy in this band. These lines are of extreme importance to radio astronomy.

13. 1718.8-1722.2 MHz: See Comment 11, which applies here also.

Justification (11, 12, 13)

A relatively new and very exciting branch of astronomy is astrochemistry. This subject involves the study of the formation of molecules in space and their abundance. In 1963, OH, the hydroxyl radical, was the first molecule to be detected at radio frequencies. Today, radio astronomers have detected about 80 different organic and inorganic molecules in space. Space chemistry is vital in understanding the physics of stars and planets. The OH molecule has been observed widely in our galaxy in its ground-state transitions at 1665 and 1667 MHz and its satellite lines at 1612 and 1720 MHz. OH has been detected in thermal emission and absorption in several hundred different molecular complexes in our galaxy. Besides the thermal emission, extremely narrow and intense emission lines have been seen in certain galactic regions. This emission is due to maser action and can be associated with star-forming regions and with more evolved stars.

The study of OH and other characteristic molecules is thus of great interest for investigating the physical phenomena associated with the formation of protostars and the initial stages of star formation. Observations of OH maser sources using the powerful technique of very-long-baseline interferometry (VLBI) have shown that the masing regions have apparent angular sizes on the order of 0.01 arc second or less. Such apparent sizes translate to linear sizes of the order of a few times the mean distance between the earth and the sun (150 million kilometers) and occur at the heart of regions with active star formation. The technique of VLBI makes use of two or more widely separated radio telescopes (tens to several thousands of kilometers apart), and simultaneous observations are made with time synchronization provided by atomic clocks. The data are recorded on magnetic tape at each telescope or are communicated via satellite and recorded elsewhere. At a later time the data from the different stations are correlated using the accurate time signals recorded with the data. The angular resolution achieved with such techniques depends not on the size of the individual telescopes but on the distance between them. VLBI observations have a great impact on the study of molecular emission regions in space, the nuclei of galaxies, and even of terrestrial processes, such as plate tectonic movement. The United States is building a dedicated system of ten VLBI telescopes from Hawaii across the continent to the Virgin Islands called the VLBA, or Very Long Baseline Array, which will achieve unprecedented resolution.

Hydroxyl (OH) and other molecules are being used to study the spatial distribution of the molecular component in our galaxy and other galaxies. OH can be seen in other galaxies by absorption against radio sources in galactic nuclei and by maser emission. The OH megamaser emission from galactic nuclei can be more than a million times more luminous than galactic masers and can be seen to great distances. The present redshift limit for extragalactic masers is 50,000 km/s ($z = 0.17$), which causes the OH line to be observed at 1428 MHz. These powerful megamasers are due to maser action within the cores of galaxies; this action results in amplification (rather than absorption) of the nuclear radio continuum. Use of the

OH line to study these very peculiar and active galaxies allows radio astronomers to diagnose the temperature and density of the molecular gas in the center of these galaxies.

Emission lines from ^{18}OH and ^{17}OH have been detected in some molecular regions of our galaxy. The data from these lines allow the study of the abundances of the oxygen isotopes involved. Such studies are a crucial part of understanding the network of chemical reactions involved in the formation of atoms and molecules. The data can help astronomers to understand the physics of stellar interiors, the chemistry of the interstellar medium, and the physics of the early universe.

Comments

14. 2200-2290 MHz: This band is widely used in conjunction with the Space Research band just above it. This usage allows radio scientists to use space tracking equipment to support astronomical observations and radio telescopes to support important space missions. In particular, major geodetic and astrometric programs are being carried out jointly in the frequency range 2200-2300 MHz.

15. 2290-2300 MHz: This band, allocated to Space Research (Deep Space and Space-to-Earth), can also be used for VLBI observations in radio astronomy. A secondary shared status should be sought in this band.

16. 2655-2690 MHz: This is an important extension of a useful, but too narrow, continuum band at 2690-2700 MHz. The broadcast satellite service, at present allocated as one of the users of the band at 2655-2690 MHz, interferes with radio astronomy when it broadcasts from space to the earth in channels adjacent to the radio-astronomy band. A domestic agreement has been made for the satellite service to be implemented starting from the bottom of the band at 2500 MHz and then proceeding to higher frequencies. This should leave the 2670-2690 MHz band free of interference for some years.

17. 2690-2700 MHz: This band, while useful and fulfilling the octave-need requirement, is narrow relative to most of the continuum bands currently allocated to the Radio Astronomy Service. If possible, the width of the band should be increased. In passive sensing, it is used for measurement of soil moisture and sea surface temperature.

Justification (14, 15, 16, 17)

The study of the continuum emission of radio sources requires observations throughout a very wide frequency range. The spectral regions at 2200 to 2300 MHz and 2655 to 2700 MHz are excellent bands for continuum measurements partly because the galactic background radiation is low. Observations of thermal and nonthermal radio sources at these frequencies help to define the shape of their spectra, which in turn can give information on the physical parameters of the radiating sources such as densities, temperatures, and magnetic fields. The knowledge of these physical parameters is essential to explain the physical processes that operate in radio sources to produce radio radiation. Many extragalactic radio sources show a "break" in their nonthermal spectrum in the region between 1 to 3 GHz, and continuum measurements in the range of 2 to 3 GHz are essential to define such a spectral characteristic accurately. The spectral "break" at relatively high frequencies from synchrotron sources is closely related to the lifetime of relativistic particles in radio galaxies and quasars. Such information is crucial to our understanding of the physical processes taking place in radio sources.

These frequency bands are also useful for galactic studies of ionized hydrogen clouds and the general diffuse radiation of the galaxy. Since, at such frequencies, available radio telescopes have adequate angular resolution (narrow beams, of the order of 10 arc minutes for large telescopes), many useful surveys of the galactic plane have been performed, including the regions of the galactic center, which is invisible at optical wavelengths because of the interstellar absorption by dust particles. The center of our galaxy is perhaps its most interesting region, and it can only be observed at infrared and radio wavelengths, since such long wavelengths are not affected by the dust particles in interstellar space. The study of the nuclei of galaxies, including the nucleus of our own galaxy, is emerging as an extremely important and fundamental topic in astronomy. Problems that can be studied in these objects include the state of matter and the possibility of the existence of black holes in galactic nuclei; the explosive activities and the production of intense double radio sources from galactic nuclei; the influence of galactic nuclei on the morphological structure of galaxies; the formation of galaxies and quasars; and many other relevant and major astrophysical topics.

An important study at radio wavelengths is the polarization of the radiation that is observed from radio sources. Radio sources are often found to be weakly linearly polarized, with a polarization angle that depends on frequency. This effect is due to the fact that the propagation medium in which the radio waves travel to reach us is composed of charged particles, electrons, and protons, in the presence of magnetic fields. The determination of the degree and angle of polarization gives us information on the magnetic fields and electron densities of the interstellar medium and in certain cases on the nature of the emitting sources themselves. The degree of polarization of radio waves is higher at higher frequencies. The frequency bands near 2300, 2700, and 5000 MHz are important bands for polarization measurements.

Comments

18. 4825-4835 MHz: The formaldehyde (H_2CO) line is one of the four or five most important spectral lines in radio astronomy. CORF urges that the current footnote be upgraded to a narrow, exclusive, worldwide allocation. See Comments 19 and 20 below.

19. 4800-4990 MHz: This is an important extension of a heavily used, but too narrow, continuum band at 4990-5000 MHz. CORF supports its allocation to radio astronomy on a shared basis with fixed and mobile services, which has been implemented in all three regions but not in the United States.

20. 4990-5000 MHz: This band, while useful in fulfilling the octave-need requirement, is narrow relative to most of the continuum bands currently allocated to the Radio Astronomy Service and is also useful for passive remote sensing of the earth. If possible, the width of the band should be at least doubled. If this band could be widened to include the H_2CO line (see Comment 19) or widened and moved to include the 4830-MHz H_2CO line, not only would the H_2CO be afforded exclusive, worldwide protection, but the radio-astronomy continuum band could also be placed to avoid interfefence from the Microwave Landing System above 5000 MHz. In either case, a 1- to 2-percent bandwidth is most desirable. This band is also important for passive sensing of the earth.

Justification (18, 19, 20)

Formaldehyde (H_2CO) is detected in interstellar clouds at 4829.66 MHz. The H_2CO line at this frequency is considered to be one of the most important radio lines in the entire spectrum, primarily because it can be detected in absorption in almost any direction where there is a continuum radio source. The distribution of H_2CO clouds can give independent evidence of the distribution of the interstellar material and can help in understanding the structure of our galaxy. H_2CO lines from the carbon-13 isotope and oxygen-18 isotope have been detected, and studies of the isotopic abundances of these elements are being carried out.